Beyond Standard Model : Report of Working Group II

Workshop on High Energy Particle Physics 3 (Madras, Jan. 10–23, 1994)

Anjan S. Joshipura

Theory Group, Physical Research Laboratory
Navrangpura, Ahmedabad 380009, India

and

Probir Roy

Theory Group, Tata Inst. of Fundamental Research
Homi Bhaba Road, Bombay 400005, India

Participants:
K.S. Babu, B. Brahmachari, C. Burgess, G. Datta, S. Goswami, A. Joshipura A. Kundu, Mohan Narayan, S. Nayak, M. V. N. Murthy, M.K. Parida G. Rajasekaran, S. Rindani, Probir Roy, J.W.F. Valle

Abstract

Working group II at WHEPP3 concentrated on issues related to the supersymmetric standard model as well as SUSY GUTS and neutrino properties. The projects identified by various working groups as well as progress made in them since WHEPP3 are briefly reviewed.

Working group II (WGII) identified definite topics each of which was intensively discussed within the corresponding subgroup during the workshop. Significant progress was made in some of them and some of the projects have been completed in the meantime. The following is the list of the projects addressed by WGII:

- Evolution of R parity violating couplings (*B. Brahmachari and P. Roy*)
- Beyond S, T and U (*A. Kundu and P. Roy*)
- Neutrino masses and proton lifetime in SUSY $SO(10)$ (*K.S. Babu, M.K. Parida and G. Rajasekaran*)
- Degenerate neutrinos(*K.S. Babu, C. Burgess, A.S. Joshipura, S. Rindani, J.W.F. Valle*)
- Solar and atmospheric neutrino problems with three generations (*G. Datta, S. Goswami, A. Joshipura, M.V.N. Murthy, Mohan Narayan, G. Rajasekaran and S. Rindani*)
- Magnetic moments for heavy neutrinos (*K.S. Babu, S. N. Nayak and P. Roy*)
- Extraction of neutrino magnetic moment from experiments (*M.V.N. Murthy, G. Rajasekaran and S. Rindani*)
- Evolution of couplings in SUSY LR model (*B. Brahmachari*)

1 Evolution of R violating couplings

Brahmachari and Roy [1] studied the evolution of the baryon number and R-parity violating Yukawa couplings in the supersymmetric standard model and derived bounds on them from the requirement of perturbative unitarity. They added the following terms to the superpotential of the minimal supersymmetric standard model (MSSM):

$$\mathcal{L} = \lambda^{'''}_{ijk}(D^c_i D^c_j U^c_k), \tag{1}$$

where U^c, D^c denote the anti quark superfields and i, j, k are generation indices. These terms violate both R parity and the baryon number. Unlike the analogous lepton number violating terms, the presence of the above terms by themselves is not significantly constrained from low energy considerations. Interesting bounds on these couplings can nevertheless be obtained by requiring that all the Yukawa couplings Y remain less than unity till the grand unification scale $M_U \sim 2 \times 10^{16}$ GeV is reached.

Assuming only λ'''_{133} and λ'''_{233} to be large, they set up the RG equations for the relevant couplings. The requirement of perturbative unitarity was shown to lead to an upper bound in the range 0.5-0.6 on the baryon number violating Yukawa couplings, the exact value being dependent on the top quark mass as well as on the ratio $\tan\beta$ of the Higgs vevs. It was also shown that the fixed point value of the top Yukawa coupling was somewhat reduced compared to that in the MSSM because of the presence of the additional baryon number violating Yukawa couplings.

2 Oblique corrections beyond the linear approximation

The lectures of C. Burgess (included in the proceedings) discussed the question of going beyond the linear Q^2-expansion approximation used in 1-loop oblique electroweak radiative corrections and the new oblique parameters V, W, X and Y. A. Kundu and P. Roy afterwards examined the same question in another way. They formulated q^2-expansion independent definitions of S, T, U which are different from those of Burgess, Maksymic and London. The difference concerns the broken and custodial symmetry contents of these parameters. Kundu and Roy extended the Peskin-Takeuchi definitions beyond the linear approximation whereas BML did the same with the Marciano-Rosner definitions. The BML and KR definitions differ in terms of weak isospin and hypercharge breaking properties; the choice of definition can be regarded as a matter of convenience but different definitions mean different physical quantities. Kundu and Roy have further found the organizing principle behind the q^2-expansion approximation — namely that it is needed in calculating the Z- and W-wavefunction renormalization constants. Stringent experimental bounds are obtained on S, T and U without reference to this approximate procedure. The new oblique parameters V, W, X, Y have been bounded [2] experimentally within quite tight ranges for the first three.

3 Neutrino masses in SUSY $SO(10)$

K. S. Babu, M. K. Parida and G. Rajasekaran looked at the issue of obtaining neutrino masses in the experimentally interesting range in the context of supersymmetric $SO(10)$ models. The neutrino masses needed for solving the solar neutrino problem arise naturally in and $SO(10)$ if the Majorana masses of the right handed neutrinos are in the intermediate range $\sim 10^{10}$ GeV [3]. The generation of such masses through

the vacuum expectation values of the chargeless scalars in the $126+\bar{126}$ representation in SUSY $SO(10)$ models requires [4] some assumptions of the extended survival hypothesis. The aim of the project was to provide an alternative mechanism for generating the right handed neutrino masses in the intermediate energy range.

The following breaking chain was considered:

$$SO(10) \longrightarrow G_I \longrightarrow G_{SM}, \tag{2}$$

where $G_I = SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ or $SU(4)_c \times SU(2)_L \times SU(2)_R$ and was assumed to break at a scale $M_I \sim 10^{14} GeV$. Although the representation $126+\bar{126}$ was present it did not acquire a vev. The right handed neutrino masses were induced by the presence of the $16+\bar{16}$ representation to be

$$M_{N_R} \sim \frac{M_I^2}{M_U}. \tag{3}$$

This could be significantly lower than the value $M_{N_R} \sim M_U \sim 10^{16}$ GeV permitted in a single step breaking.

4 Degenerate neutrinos

It has recently been realized [5, 6] that simultaneous solutions of the solar and atmospheric neutrino deficits as well as of the dark matter problem with a hot component of about 30% require almost degenerate masses for the three neutrinos. Such a spectrum was shown to arise in a natural manner in left right symmetric models augmented with a suitable generation symmetry [5, 6]. The aim of the working group was to discuss issues related to the construction of realistic grand unified models following the scenario proposed in refs. [5, 6]. In particular one should obtain (a) the common degenerate mass in the eV range (b) mass splittings appropriate for the solar and the atmospheric neutrino problems and (c) the right mixing pattern. The required mass splitting arise naturally [6] if the Dirac masses for the neutrinos coincide with the up quark masses as in the simplest $SO(10)$. In this case, one obtains

$$\frac{|\Delta_{21}|}{|\Delta_{32}|} \approx \left(\frac{m_c}{m_t}\right)^2 \approx (1-3)\times 10^{-4}. \tag{4}$$

This nicely reproduces the hierarchy required to simultaneously solve the solar and atmospheric neutrino problems. The problem to be addressed was to obtain this prediction in a complete model based on $SO(10)$ preserving other successful features.

While a complete model is still lacking, significant progress was made by the members of the working group [8, 7, 10] as well as others [9] in the construction of realistic models. In particular, Valle and Ioannissyan constructed a model based on $SO(10)$ with a horizontal $SU(2)$ symmetry. In their model, the up quark mass matrix coincided with the Dirac neutrino masses leading to eq.(4). The down quark mass matrix is however not proportional to the charged lepton masses. This allows enough freedom to obtain the required mixing pattern. A similar model was also proposed by Caldwell and Mohapatra [9]. Bamert and Burgess worked out a scenario which contained a singlet fermion in addition to the three left and right handed neutrinos. A horizontal SU(2) symmetry was introduced to obtain the degenerate spectrum. The couplings involving the singlet fermion break the horizontal symmetry and lead to a departure from the degeneracy in neutrino masses. The singlet fermion was moreover used in the context of the left right symmetric theory [10] in order to understand the difference between the quark and leptonic mixing angles in scenarios with almost degenerate neutrinos. The singlet also played a crucial role in generating the required mass pattern among neutrinos in this scenario.

5 Solar and atmospheric neutrino problems with three generations

The understanding of the solar and atmospheric neutrino deficits in terms of neutrino oscillations seems to require two vastly different values for the (mass)^2 difference among neutrinos. Thus at least two neutrinos need to be massive and analysis of the solar and atmospheric neutrino data in terms of three generations becomes interesting. Such an analysis was carried out earlier [11, 12] assuming the MSW mechanism to be responsible for the solar neutrino conversion. This working group looked at a complimentary scenario in which two of the neutrinos were assumed to be almost degenerate with very small (mass)^2 difference $\sim 10^{-10}$ (eV)^2 while the other (mass)^2 difference was assumed to be in the range $\sim 10^{-2} - 10^{-3}$ (eV)^2. Thus the vacuum oscillations are responsible for both the solar and the atmospheric neutrino deficit. Since two of the relevant (mass)^2 differences show hierarchy, the oscillation probabilities involve only one more mixing angle compared to the case of two generations [11, 12]. Fixing this mixing angle ($\theta_{\mu\tau}$) to be in the range appropriate for the atmospheric neutrino problem, restrictions on other mixing angle (namely $\theta_{e\mu}$) and the (mass)^2 difference $\Delta_{e\mu}$ were determined from the data on solar neutrino deficit.

6 Neutrino magnetic moment

Two different problems were analyzed in connection with the neutrino magnetic moment. One was the issue of a large magnetic moment of a very heavy neutrino. Since the magnetic moment of fermion turns out to be proportional to its mass in a number of situations, it is interesting to ask if the magnetic moments of heavy singlet neutrinos can be large enough to dominate over their point couplings to W and Z induced by mixing with the light neutrinos. The typical magnetic moment of a very heavy right handed neutrino N was estimated from the one-loop graph and the mass-dependence was seen to come through the factor $m_L M_N (M_N^2 + M_W^2)^{-1}$, where the W couples to ℓ and N, so that there was no enhancement for $M_N \gg M_W$. Thus it was found that, contrary to naive expectation, the point couplings always dominated over the magnetic moment couplings.

The conventional procedure of extracting information on the neutrino magnetic moment coupling from the data on ν e scattering was questioned. In order to extract the magnetic moment from the data, one conventionally writes an effective phenomenological term $\kappa_\nu \sigma_{\mu\lambda} q_\lambda / m$ in the calculation of the neutrino electron scattering. An analogous treatment of the $e - p$ scattering has been shown to lead to a drastic overestimation of the QED radiative corrections [13]. By the same token, the inclusion of the neutrino magnetic moment term through the Pauli term must lead to wrong results at some energy scale. The main issue was to determine the relevant scale where the Pauli approximation breaks down. The suggestion was to do a detailed calculation of νe scattering in specific model which leads to large magnetic moment and compare it with the phenomenological result obtained assuming the Pauli term as is conventionally done.

7 Evolution of couplings in SUSY LR model

B. Brahmachari studied the 1-loop evolution of Yukawa copulings in the minimal supersymmetric left-right model. He found [14] a fixed point behaviour in the top Yukawa coupling that was rather analogous to the one one in the MSSM. He was able to explicitly exhibit the dependence of the fixed point solution of $Y_t(m_t)$ on the right-symmetry breaking scale. The predicted top mass value in this scheme was between 168 and 174 GeV. Brahmachari was also able to fix the value of the Majorana Yukawa coupling which is otherwise a free parameter.

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